Thermal Preferenda and Diel Activity Patterns of Fishes from Lake Waccamaw

W. W. Reynolds and M. E. Casterlin

Biothermal Research Institute
R. D. 3, Box 10, Wyoming, Pennsylvania 18644

AND

D. G. Lindquist [1]

Department of Biology
University of North Carolina, Wilmington, North Carolina 28406

ABSTRACT.— We tested seven fish species from Lake Waccamaw in Ichthyotron electronic shuttleboxes to determine their preferred temperatures and diel activity patterns. All preferred temperatures between 25° and 31° C, which corresponded to water temperatures measured in the lake in August 1981. All species avoided temperatures below 20° or above 36° C. One species was diurnal, two were nocturnal, and four were crepuscular in diel activity pattern under the LD 14:10 August photoperiod.

INTRODUCTION

Lake Waccamaw, North Carolina, is one of the shallow "bay lakes" of the southeastern coastal plain of North America. It is unusual among these lakes in having significant calcareous buffering capacity, and thus a pH normally at or above neutrality. Another unusual feature of Lake Waccamaw is that it harbors three endemic fish species: *Fundulus waccamensis* Hubbs & Raney, the Waccamaw killifish (Cyprinodontidae); *Menidia extensa* Hubbs & Raney, the Waccamaw silverside (Atherinidae); and *Etheostoma perlongum* (Hubbs & Raney), the Waccamaw darter (Percidae, Etheostomatinae). An undescribed ictalurid, *Noturus* sp., the broadtail madtom, also occurs in the lake.

In connection with a survey to assess the conservation status of the endemic species, we measured the thermoregulatory behavior (preferred and avoided temperatures) and diel activity patterns of several fish species. They included the three endemic and one undescribed species named above, and three others that had never been so tested—*Lepomis marginatus* (Holbrook), the dollar sunfish (Centrarchidae); *Enneacanthus chaetodon* (Baird), the blackbanded sunfish (Centrarchidae); and *Noturus gyrinus* (Mitchell), the tadpole madtom (Ictaluridae).

[1] Direct reprint requests to DGL

MATERIALS AND METHODS

The fishes (38-60 mm standard length) were captured by seine or hand net, either in the lake or in backwaters of the Big Creek tributary, and tested individually in Ichthyotron electronic shuttleboxes as described by Reynolds (1977). These devices permit a fish, by passing through an electronic gate (light beam), to control water temperatures by normal swimming movements, which are monitored automatically via phototransistors. The fish were tested during the first half of August 1981, under a natural photoperiod of 14 h light: 10 h dark (LD 14:10). Final thermal preferenda, which are independent of thermal acclimation (Reynolds & Casterlin 1979, 1980), were measured, and hourly activity as registered by the phototransistors (mean light beam interruptions per hour) were used to characterize diel activity patterns (Table 1). In general, more precise behavioral thermoregulators will show greater activity. The relative amount of activity (light beam interruptions) during day, night, and crepuscular periods is used to determine the diel patterns.

RESULTS

All species exhibited mean final thermal preferenda between 25° and 30° C (Table 1). Various measures of central tendency failed to coincide for each species because of skewness in the distributions of occupied temperatures. Of these species, *Lepomis marginatus* was the most precise behavioral thermoregulator, exhibiting the smallest range and standard deviation, while *Menidia extensa* was the least precise. Thus, the former species also exhibited the highest hourly activity rate, while the latter was the least active. *Noturus gyrinus* preferred the warmest temperatures, and *Enneacanthus chaetodon* the coolest, in terms of mean value.

Fundulus waccamensis was the only diurnal species as determined by maximal activity, while *Etheostoma perlongum* and *Noturus* sp. were nocturnally most active (Table 1). The other species were crepuscular, being most active around dawn and/or dusk. Here there was a marked behavioral difference between the two *Noturus* species, which often share the same microhabitats and nesting sites (Lindquist, unpubl.).

During the first half of August 1981, normally a time of warmest water, the temperatures in the lake ranged from 27.4° to 31.0° C over all areas and depths. Warmest temperatures occurred near the mouth of Big Creek, the major tributary. In the creek and associated canals, temperatures ranged from 24.8° to 30.9° C during the same period.

DISCUSSION

Lake Waccamaw does not normally freeze completely over in winter, nor does it stratify thermally to any significant extent in summer, as its maximum depth is only about 3 m. The temperatures preferred by the

Table 1. Thermoregulatory and diel activity characteristics of Lake Waccamaw fishes tested individually in Ichthyotron electronic shuttleboxes in August (photoperiod LD 14:10).

Species	Preferred temperatures (° C)						Interquart.	Mean Hourly activity			
	mean	S.D.	mode	median	range	midpoint	range	day	night	crep.	mean
Fundulus waccamensis	27.4	1.4	25.5	26	23-34	28.5	25-27	15.9	11.7	12.5	14.1
Menidia extensa	26.3	4.2	22	26	20-35	27.5	22-31	0.3	0.6	5.3	0.8
Etheostoma perlongum	28.4	2.5	29	29	22-33	27.5	27-30	3.9	5.5	4.0	4.5
Enneacanthus chaetodon	25.7	3.2	27	27	20-31	27.0	23-27	3.3	0.8	6.0	2.5
Lepomis marginatus	27.7	1.3	28	28	26-30	28.0	26-29	47.6	44.8	51.3	46.9
Noturus gyrinus	29.6	3.6	31	29	23-36	29.5	26-32	10.0	6.0	26.8	9.9
Noturus sp.	29.0	2.5	28	29	23-35	29.0	28-30	0.7	31.1	10.0	12.9

fishes tested correspond fairly well to normal maximum summer temperatures in the lake. This is a typical result, in that freshwater and marine fishes often prefer temperatures (final preferenda) that are normal seasonal maxima in their habitats and geographic ranges (Reynolds & Thomson 1974; Reynolds et al. 1977; Casterlin & Reynolds 1979a, 1982).

Field observations of fish distributions and movements appeared largely consistent with our laboratory measurements. For example, as inshore lake temperatures over a two-week period warmed from 27.4 °C to 29.4 °C at one location, fewer *Fundulus* and *Menidia* could be seen or captured by seine inshore during the day, although they moved inshore at night as some cooling occurred. *Enneacanthus chaetodon* was captured in the cooler depths of backwater canals, which had lower temperatures than occurred in the lake at that time. We did not see this species in the lake, where temperatures were above its mean final preferendum.

A more dramatic field example of apparent behavioral thermoregulation occurred during the unusually dry and hot summer of 1980. Diurnal temperatures in the lake shallows reached 40 °C, and all fish then vacated these lethally hot regions, at least during daylight hours (Lindquist and Yarbrough, unpubl.).

We often found males of both *Noturus* species guarding nests under the same spawning cover, and their thermal preferenda (Table 1) apparently differ little. The striking difference in their diel activity patterns (one being nocturnal, the other crepuscular and mainly active at dawn) suggests a temporal niche partitioning between these otherwise closely similar species.

The very high activity level of *Lepomis marginatus* (Table 1) is noteworthy. It apparently reflects territorial or reproductive aggression, which was occurring at that time, and may not be typical of other seasons. For example, intense agonistic interactions, with resultant body damage, was seen among individuals in holding tanks, although this could not occur during the testing of single individuals in the Ichthyotron. It is also interesting that *L. marginatus* preferred lower temperatures than *Lepomis macrochirus* Rafinesque, the bluegill sunfish, which prefers about 31 °C (Reynolds & Casterlin 1979) but ranges much farther north. *Enneacanthus chaetodon* prefers temperatures similar to those preferred by *Enneacanthus gloriosus* (Holbrook), the bluespotted sunfish (Reynolds & Casterlin 1980; Casterlin & Reynolds 1979b).

Etheostoma perlongum is only the third darter species to have been successfully tested for thermoregulatory behavior in the laboratory. Hill & Matthews (1980) reported thermal preference data for *Etheostoma spectabile* (Agassiz) and *Etheostoma radiosum* (Hubbs & Black) from the Blue River in Oklahoma, and found a correlation between thermoregulatory precision and the thermal stability of microhabitats occupied by these species in nature. In our tests, *E. perlongum* exhibited a thermoregulatory precision that was intermediate among the species tested. Lindquist et al. (1981) observed seasonal onshore-offshore spawning migrations of *E. perlongum,* which might be cued by changes in water temperature. Although darters generally appear to be diurnal (see Adamson & Wissing 1977; Cordes & Page 1980; Mathur 1973), our data suggest that *E. perlongum* is nocturnal. However, our results may not accurately represent the fish's activity pattern in nature, and further tests are necessary to resolve this apparent discrepancy.

Enneacanthus gloriosus exhibits a crepuscular activity pattern (Casterlin & Reynolds 1980), as does *E. chaetodon* (Table 1). Centrarchids generally tend to be diurnal or crepuscular (Reynolds & Casterlin 1976; *L. marginatus* in Table 1). In contrast, ictalurids such as *Noturus* (Table 1) tend to be nocturnal or crepuscular, as are the *Ictalurus* species (Reynolds & Casterlin 1977, 1978). Ictalurids and centrarchids are considered typical "warm-water" fish species (Reynolds 1979), in contrast to "cold-water" species such as salmonids that prefer temperatures below 20 °C. Percids are more variable, with various species preferring widely different temperatures (Reynolds 1979).

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